Tunable THz Source

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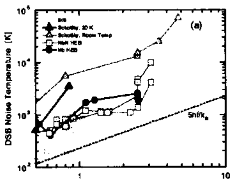
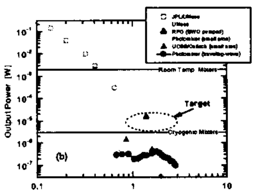
1. Introduction

Implementation of an all solid-state heterodyne receiver for frequencies above 1 THz has been hindered by the unavailability of suitable frequency sources. Figure (a) below shows that a multitude of very capable detectors are available in the 1 to 3 THz region. In contrast, Fig. (b) shows the best presently demonstrated sources (fundamental sources followed by Schottky diode multiplier chains). The graph illustrates that the present photomixer performance level is inferior below 1 THz when compared with the multiplier chains. Above that threshold, however, these photonic type devices remain the only demonstrated sources.

Our goal is to actively pursue improved photomixer designs which hold promise to increase the output powers by an order of magnitude above current levels and thus make these devices useful as local oscillator sources for an all-solid heterodyne receiver implementation.

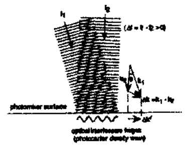


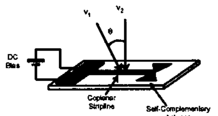


2. Background

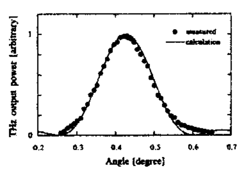
We have demonstrated that a traveling-wave photomixer design is capable of generating an order of magnitude more power than earlier small-area design above 1.5 THz. This is because the RC-time constant associated with the interdigitated electrode structure is eliminated.

The traveling-wave requires the two incident wavelength optical beams to be incident at a slight angle, such that the velocity of the optical interference fringe matches the group velocity of the generated rf wave along the photomixer surface (*Appl. Phys. Lett. 74, 2872 (1999)*).





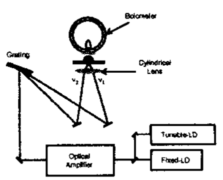
Implementation of a traveling-wave photomixer.



Experimentally determined phase-matching and comparison with the theoretical expression:

$$\text{Phase Match} = \frac{\sin^2\left(\frac{\Delta k^{\parallel} L}{2}\right)}{\left(\frac{\Delta k^{\parallel} L}{2}\right)^2}$$

The angle must be carefully controlled to obtain optimal phase-matching. In the experimental setup we first assured perfect mode-matching of the pump lasers by seeding a single optical amplifier with two laser diodes. The wavelengths are then split using a grating and separate mirrors control the final incident angles.

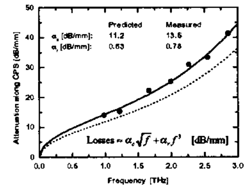


3. Concept

We have initiated a development effort at JPL, in collaboration with UCSB and Caltech, to further improve upon the traveling-wave type photomixer to achieve breakthrough THz output powers. The primary focus of our activity is in the following areas:

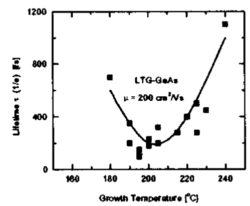
3.1. Membrane photomixer

The experimentally measured losses of the present traveling-wave device grows dramatically above 1 THz. The losses, on the order of several 10's of dB/mm, is caused by power coupling into substrate modes of the GaAs wafer/Si-lens. This loss mechanism is eliminated when the GaAs substrate is thinned by selective etching. When the remaining photoconductive active layer is only a few microns thick all substrate modes will cut-off.

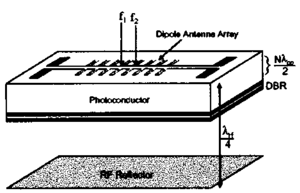


3.2. Novel materials

The low-temperature-grown GaAs material, which has been used exclusively in the past to make photomixer devices, displays several undesirable properties, e.g. difficult to control lifetime, susceptibility to elevated temperatures, poor thermal conductivity, dramatically reduced mobility (~200 cm²/Vs), and a large bandgap (1.42 eV ~ 0.87 μm). We are in the process of synthesizing novel material structures (ErAs islands in GaAs, InGaAs and InAlAs) which address many of the short-coming above. Most desirable, these smaller bandgap materials may be usable at longer IR wavelength (1.06 to 1.55 microns) and thus can take advantage of a wide range of commercial fiber-optic components.

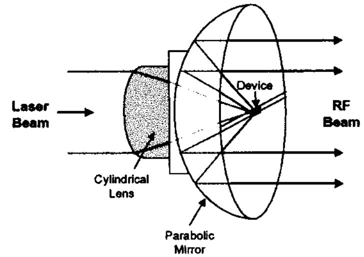


3.3. Device RF Circuit Topology



The device consists of a thin membrane photo-conductive material which forms a resonant cavity at the optical input wavelength. The distributed Bragg reflector (DBR) at the bottom of the cavity assures a second pass of the laser beams. As indicated, the laser beams are incident from the top and cause the excitation of two oppositely traveling-wave at the difference frequency along the coplanar stripline (CPS). The CPS is periodically loaded with dipole antennas to couple the radiation into free-space. A back-reflector is used to steer all emitted radiation in the forward direction (upwards).

The device is mounted at the focus of a parabolic mirror by a support struts suspended across the opening. A cylindrical lens focusses the laser beams through a small opening in the mirror onto the gap between the lines of the CPS. The emitted radiation is collected and collimated by the mirror in the forward direction. Since the opening of the mirror is easily made larger than several 10's of λ_{rf}, the exiting beam will be highly collimated.



4. Present Status

Professor Gossard's group at UCSB has made progress developing a new approach for synthesizing materials which allows engineering of the carrier lifetime by adjustment of the growth parameters. We are surmising that with this approach we are able to grow materials which can be used at longer wavelengths. Isolation of GaAs:ErAs membranes has been initiated at JPL to characterize prototype device designs.

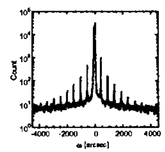
4.1. Material Synthesis (UCSB): Development of ErAs Islands in GaAs

Microstructure: Transmission electron microscopy and X-ray diffraction show the high quality of the material:

- Size, shape and arrangement of islands.
- Coherency of the crystal.

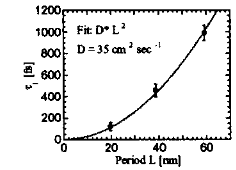
(in print *J. Vac. Sci. Technol. B.*)

Plan view TEM.

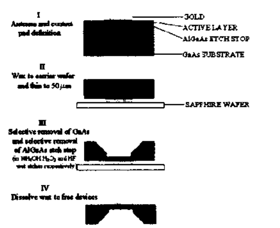


X-ray rocking curve.

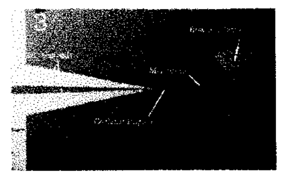
Photocarrier life time: Engineering control over carrier life time via superlattice period. (*Appl. Phys. Lett. 75, 3548 (1999)*).



4.2. Membrane Fabrication GaAs:ErAs Samples



Left panel illustrates the process flow used to isolated the membrane. A finished prototype device is shown in the photograph below. The 0.5 μm-thick membrane exists below the CPS and the center of the bowtie antenna.



5. Summary

We are pursuing a photomixer design that is both capable of very high frequency operation and accomplishes efficient coupling of the rf radiation into free-space. The adherence to phase-matching, as was needed with the original traveling-wave photomixer design, is no longer as critical since an array of λ/2-spaced dipole antennas is used. This eliminates the difficult task of careful angle adjustment of the pump beams. Further, the elimination of the Si-lens, and hence the losses associated with reflections and excitation of substrate modes, will result in higher output powers. Demonstration of the concepts presented will be actively pursued by JPL and the University partners in the coming year.

R. Wyss, et al., Space Astrophysics Detector Workshop, Baltimore, MD, June 20-30, 2000.